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TUNABLE RING LASER WITH EXTERNAL GRATING OPERATING IN A SINGLE MODE

Technical Field of the Invention

The present invention relates to an optoelectronic
device, and in particular to a lasing device that can
change an emitted wavelength at high speed.

Description of Related Art

Tunable lasers are commonly used as sources in high
capacity optical telecommunication systems, such as dense
wavelength division multiplexing (DWDM) systems. This
technique involves transmitting several optical signals
via a single fibre with the optical signals having
slightly differing respective wavelengths or frequency.
A related technique, known as wavelength routing,
involves transmitting data using precise wavelengths and
rapidly interchanging between those wavelengths. Tunable
lasers are also used in photonic switching systems and
also find application in other fields, such as
spectroscopy and optical sensing.

Examples of conventional tunable semiconductor diode
lasers used for optical communications are listed below.

A first type is known as a " Y-cavity laser" (see M.J.
Kuznetsov, J. of Lightwave Technology, Vol.12, Issue 12,
Dec 1994), in which extended tuning (near 40 nm) is
achieved by adopting an external interferometer.
However, Y-cavity lasers suffer from a limited side mode
suppression ratio (SMSR) of less than 25dB.

A second type of conventional tunable laser is known as
"grating assisted co-directional coupler (GACC) laser"
(see Z.M. Chuang, and L.A. Coldren, IEEE J. of Quantum

Electronics, Vol.29 Issue 4, April 1993), which also
suffers from a limited SMSR, due to broadening of a gain-
filter bandwidth whilst the laser is tuned. It also needs
a multiple of control electrodes making tuning
complicated.

A third type of conventional tunable laser is the
distributed Bragg reflector (DBR) laser family,
particularly a device known as a "sampled grating
distributed Bragg reflector (SGDBR) laser" which offers a
wide tuning range (see L.A. Coldren, IEEE J. of Selected
Topics in Quantum Electronics, Vol. 6, Issue 6, Nov-Dec.
2000 and references therein; F. Delorme, IEEE J. of
Quantum Electronics, Vol.34 Issue 9, Sep. 1998). In
order to set an operating wavelength or frequency for
SGDBR lasers it is necessary to determine at least three
control variables. Each control variable is an external
current source with a value determined from a multi-
dimensional look-up table (which must be pre-programmed
in a time consuming 'training' process). The process of
determining the control variables involves processing in
several different zones in the multi-dimensional variable
space. The slow speed of this processing leads to an
inadequate tuning speed for efficient operation of, for
example, optical packet transmission systems. This
problem is further compounded by transient phenomena in
the laser cavity which have relatively long decay times
(such as thermal stabilizing time for the grating).
SGDBR lasers generally include phase matching components
which add complexity and increase the dimensions of the
device.

In addition, a further type of tunable laser is a ring
laser with intra-cavity tuning means such as a grating
distributed reflector or tunable optical filter. This
generally comprises a ring cavity laser with a grating or

filter forming at least part of the ring cavity. Known
devices generally use rare-earth doped optical fibre to
form the ring cavity laser. However, where a tuning
mechanism is a part of the ring cavity and the laser
cavity circumference is relatively short, then problems
similar to those encountered in tunable SGDBR lasers
arise. Further, the circumference of the ring cavity
determines the photon lifetime and thereby also affects
the speed with which such known devices can be tuned.
Thus, a greater circumference is associated with a slower
frequency tuning speed. (For example, a fibre ring cavity
laser generally has a circumference of greater than 1m
and thus a photon round trip time of greater than 5
nanoseconds. Therefore, in such known devices, a tuning
speed on a nanosecond timescale is not possible.)

Therefore, the present invention seeks to provide a
tunable laser in which the problems of conventional
tunable lasers are at least alleviated.

Summary

According to a first aspect of the present invention,
there is provided a lasing device comprising a ring
cavity, a coupling means for extracting laser emission
from the ring cavity, and a frequency selection means in
connection with the coupling means, wherein the frequency
selection means is operable to feed back part of the
extracted laser emission into the ring cavity and to
select the frequency of the feedback signal, and the
frequency selection means is not part of the ring cavity.

The tunable lasing device as described above can be
utilised in an optical communication system.

According to a second aspect of the present invention, there is provided a method of changing a lasing frequency of a ring cavity laser, the method comprising operating the ring cavity laser at a first ring cavity resonant frequency, wherein the first ring cavity resonant frequency substantially coincides with a first reflecting frequency of a frequency selection means, controlling the frequency selection means to change the first reflecting frequency to a second reflecting frequency, and operating the ring cavity laser at a second ring cavity resonant frequency, wherein the second ring cavity resonant frequency substantially coincides with the second reflecting frequency of the frequency selection means.

Furthermore, the frequency selection means of the present invention is not part of the ring cavity, i.e., the ring cavity is close-looped and will work as a resonant cavity without the frequency selection means.

Advantageously, the tunable laser of the present invention emits precise, discrete wavelengths as determined by the cavity modes of the ring laser cavity. These modes are determined during laser manufacture and can be precisely trimmed to the accurate values required.

Further advantage is gained in that the lasing frequency tuning occurs at a high speed (potentially in the order of nanoseconds). Primarily, four factors contribute to achieving this high speed tuning. Firstly, a frequency selection means which operates at a high speed is used. Secondly, a lasing frequency lock-in time of the present invention is shorter than that of conventional tunable lasers. Lasing frequency lock-in time refers to the time for an output frequency to stabilize to a predetermined value. Thirdly, only a single control variable needs to

be determined in order to set an operating frequency for
the tunable laser. Fourthly, after the initial lasing
frequency lock-in time, the emitted frequency is no
longer affected by possible long-term transience (such as
thermal drift of the frequency selection means). In this
way, the time required for the tunable laser to change
between different emitted frequencies is minimized and
also, phase matching components (as required in some
SGDBR lasers) are not necessary. Furthermore, the
preferred embodiments of this invention have a ring
cavity circumference of a few millimetres in length,
which is considerably shorter than that of conventional
tunable fibre ring devices. Laser devices of this short
cavity length are capable of high speed tuning owing to
the short photon lifetime in the ring cavity.

Brief Description of the Drawings

For a better understanding of the present invention, and
to show how it may be put into effect, reference will now
be made, by way of example, to the accompanying drawings
in which:

Figure 1A is a schematic diagram of a tunable laser in
accordance with an embodiment of the present invention;
Figure 1B shows a graph illustrating single mode laser
operation of the tunable laser of Figure 1A;
Figure 2A illustrates an enlarged cross-section of an
optical gain element of a first implementation of the
present invention;
Figure 2B illustrates a plan view of a ring cavity laser
of a first implementation of the present invention;
Figure 2C illustrates an enlarged cross-section of a
grating element of a first implementation of the present
invention;

Figure 3A illustrates an enlarged cross-section of an
optical gain element of a second implementation of the
present invention;
Figure 3B illustrates a plan view of a ring cavity laser
of a second implementation of the present invention;
Figure 3C illustrates an enlarged cross-section of an
optical coupler of a second implementation of the present
invention;

Figure 3D illustrates an enlarged cross-section of a
grating element of a second implementation of the present
invention; and
Figure 4 illustrates a ring cavity laser of a third
implementation of the present invention.

Detailed Description of Preferred Embodiment

In the tunable laser 100 of Figure 1A, a ring cavity 102
(comprised of a passive optical waveguide) and an optical
gain element 104 are connected to a bi-directional
optical output coupler 106. The optical output coupler
106 has a first port 108 and a second port 110. The
first port 108 is coupled to an output optical fibre 112
and a second port 110 is coupled to a frequency selection
means 114 (such as a grating).

In operation, the optical gain element 104 provides
optical gain within a predetermined spectral range and
the ring cavity 102 provides a propagation route for
circulating photons at one or more frequencies within the
predetermined spectral range. A laser oscillation in the
ring cavity 102 occurs at a laser frequency within the
gain spectral range when two operating conditions are
met. First, the total optical gain at that laser
frequency f_L exceeds the total optical loss in the ring
cavity 102, and second, the optical phase delay

associated with a round trip of a photon within the ring cavity 102 is a multiple of 360 degrees.

The graph of Figure 1B illustrates single mode operation of the ring cavity tunable laser 100. The upper section 118 plots the cavity mode frequencies 120 of the ring cavity 102 and shows the laser gain profile 122, and the lower section 124 plots the reflection frequencies 126 of the frequency selection means 114. Where one of the cavity mode frequencies 120 coincides with one of the grating reflection frequencies 126 single mode laser operation is achieved at frequency f_L.

The gain spectral range of the optical gain element 104 (for example, comprising a semiconductor gain medium) usually has a large bandwidth and therefore allows multiple optical frequencies to oscillate at the same time. The cavity mode frequencies 120, f_m, of the ring cavity 102 are primarily determined by the following relationship;

$$f_m = \frac{mc}{nL}$$

where n is the effective refractive index of the ring cavity 102, L is the circumference of the ring cavity 102, (in combination nL is the ring cavity optical path length), m is an integer, and c is the speed of light in a vacuum. The ring cavity mode frequency interval Δf is given by;

$$\Delta f = \frac{c}{nL}$$

Clearly, varying the circumference of the ring cavity 102 results in altered ring cavity modes 120. Where a frequency selection means 114 has multiple reflecting frequencies 126 (as illustrated in the lower half of

Fig. 1B), rather than a single reflecting frequency, it is
necessary that the reflection frequency intervals of the
frequency selection means 114 differ from the ring cavity
mode frequency intervals Δf.

Laser emission is initiated by the injection of a pumping
energy (e.g., an electric current) into the optical gain
element 104. The photon population is increased as the
photons pass through the optical gain element 104 until
the population gain exceeds the population loss within
the ring cavity. Laser output is obtained when the
photons exit the ring cavity via the bi-directional
output coupler 106.

The frequency selection means 114 selects the lasing
frequency of the ring cavity 102 from one of the many
ring cavity resonant frequencies. Light output at the
selected resonant frequency is reflected and fed back
into the ring cavity, thereby enhancing the lasing at the
selected ring cavity resonant frequency and suppressing
lasing at other ring cavity resonant frequencies due to a
mode competition process. This process allows the
establishment of lasing at the selected frequency in a
short time duration, usually a few nanoseconds. Further,
because the selected lasing frequency is determined by
the ring cavity according to above formulae, the
reflecting frequency band of the frequency selection
means only needs to approximately align with the selected
ring cavity resonant frequency to allow sufficient
optical feedback. Furthermore, after the establishment of
the lasing frequency, any small change in the frequency
selection means 114 does not affect the lasing frequency.

High speed tuning between single mode laser operation at
a first and a second ring cavity mode frequency is
achieved in the following way. A first set of reflection

frequencies of the frequency selection means 114 is
determined by applying a first control signal (such as
injecting a first current) into the frequency selection
means 114 to set a first value to a physical property
(such as refractive index) of the frequency selection
means 114. Where one of the first set of reflection
frequencies of the frequency selection means 114 is the
same as a ring cavity resonant mode frequency, photons at
this first frequency are fed back into the ring cavity
102 from the frequency selection means 114, and lasing
occurs at this first ring cavity mode frequency. Next, a
second set of reflection frequencies of the frequency
selection means 114 is determined by applying a second
control signal (such as injecting a second current) into
the frequency selection means 114 to set a second value
to a physical property (such as refractive index) of the
frequency selection means 114. Where one of the second
set of reflection frequencies of the frequency selection
means 114 is the same as a second ring cavity mode
frequency, photons at this second frequency are fed back
into the ring cavity 102 from the frequency selection
means 114, and lasing occurs at this second cavity mode
frequency.

Furthermore, prior to applying the second control signal
(such as injecting the second current) into the frequency
selection means 114, the pumping level of the optical
gain element **can be** reduced to a level less than the ring
cavity lasing threshold (which has the effect of
switching off the ring cavity laser). After injecting
the second current into the frequency selection means
114, the pumping level of the optical gain element is
increased to the original level. This has the effect of
switching on the ring cavity laser, and so lasing can
occur at the second cavity mode frequency.

The alteration of the control signal such as injected
current into the frequency selection means 114 can change
the effective refractive index of the frequency selection
means 114, and therefore the reflection frequencies of
the frequency selection means 114 in approximately 1
nanosecond.

The optical gain element 200 of a first implementation
illustrated in Figure 2A is comprised of a substrate base
202 (such as an III-V semiconductor wafer) onto which an
optically active layer 204 is deposited. Further, a
semi-insulating semiconductor layer 206, an upper
cladding layer 208, a contact layer 210 and finally,
ohmic contacts 212 form the upper part of the optical
gain element 200.

Figure 2B shows a complete ring cavity laser 214
including the optical gain element 200 of Figure 2A and a
grating element 216 of Figure 2C, all of the first
implementation. The fabrication process of the ring
cavity laser 214 is now described.

In a first epitaxial growth step, an optically active
layer 204 that provides optical gain is deposited on the
substrate 202. The substrate 202 consists of multiple
layers of InGaAsP quaternary compound semiconductor
deposited on an Indium Phosphide (InP) substrate. In the
area where the grating element 216 is to be fabricated,
the surface is patterned by a photolithography or an
electron beam lithography process, followed by an etching
process, to form grating corrugations 218. The optically
active layer 204 is then removed from the substrate 202
except for areas where the optical gain element 200 and
the grating element 216 are to be fabricated.

In a second growth step, an optically passive or
transparent layer 220 is deposited on the substrate 202
in areas where the optically active layer 204 has been
removed. The position of this optically passive layer 220
is vertically aligned to that of the optically active
layer 204 (and the thickness of both layers are
comparable). The ring cavity laser 214 is then completed
by a photolithography process that defines ridge
waveguides which form the ring cavity 222, the output
coupler 224 and the grating element 216. The entire
structure is buried in the semi-insulating semiconductor
layer 206 (except for the top of the waveguides) and the
upper cladding layer 208 and the contact layer 210 are
grown on top. The ohmic contacts 212 are then formed on
the optical gain element 200 and the grating 216.

The grating element 216 illustrated in Figure 2C is
generally a sampled grating reflector formed in a similar
way to the optical gain element 200 of Figure 2A.

The lasing and tuning operations of the first
implementation of the ring cavity laser 214 (shown in
Figures 2A, 2B and 2C) are as described for the
embodiment of the invention in Figures 1A and 1B and will
not be repeated here for the sake of brevity.

The optical gain element 300 of the second implementation
illustrated in Figure 3A is comprised of a substrate base
302 onto which an optically passive layer 304 is
deposited. A spacer layer 306 and an optically active
layer 308 form the upper part of the optical gain element
300. The optically active layer 308 forms active
vertical couplers with the optically passive layer 304
underneath (thereby creating a photonic integrated
circuit (PIC)).

Figure 3B shows a complete ring cavity laser 310
including the optical gain element 300 of Figure 3A, the
output coupler 312 of Figure 3C and the grating element
314 of Figure 3D, all of a second implementation. Each
feature is monolithically integrated onto the substrate
302. The fabrication process of the ring cavity laser
310 is mainly as described for the first implementation
of the invention in Figures 2A to 2C, with the following
exceptions.

The passive ring cavity waveguide 316 and the output
coupler 312 are formed in the optically passive layer
304. In order to achieve this, the optically active
layer 308 is removed from the substrate 302 in these
areas.

The grating element 314, like the gain element 300, is
formed in the optically active layer 308. In these areas
the active layer is not removed. Light can therefore
coupled from the passive layer into the active layer,
either to experience optical amplification in the gain
element or to interact with the grating element. During
fabrication the width of the waveguide, in the area
designated for the grating element 314, is periodically
varied to form the grating. Alternatively, the grating
element 314 can be formed by the etching corrugations in
the waveguide.

The lasing and tuning operations of the second
implementation of the ring cavity laser 310 (shown in
Figures 3A, 3B 3C and 3D) are as described for the
embodiment of the invention in Figures 1A and 1B and will
not be repeated here for the sake of brevity.

Figure 4 shows a complete ring cavity laser 400 of a
third implementation. A ring cavity waveguide 402, an

optical gain element 404, a grating element 406 and an
output coupler 408 are hybrid integrated onto a planar
substrate 410. The fabrication process of the ring
cavity laser 400 involves deposition of several optically
passive layers (not specifically illustrated) onto the
substrate 410 which are used to form the ring cavity
waveguide 402 and the output coupler 408.

The optical gain element 404 is a semiconductor optical
amplifier which is positioned in a gap where the ring
cavity waveguide 402 has been removed for that purpose.
The length of the gap is suitable for efficient butt-
coupling of light into and out of the semiconductor
optical amplifier 404. The grating element 406 is
separately fabricated in a semiconductor waveguide
material and butt-coupled to one of the output waveguides
412 of the ring cavity laser 400.

Preferably, reflection at the butt-coupled joints is
minimized. In order to achieve this, it may be necessary
to utilize a non-perpendicular angle between the end-
facets of the gain element 404 or grating element 406 and
the waveguides 402 412. Other anti-reflection means,
such as optical coatings can also be employed.

The lasing and tuning operations of the third
implementation of the ring cavity laser 400 (shown in
Figure 4) are as described for the embodiment of the
invention in Figures 1A and 1B and will not be repeated
here for the sake of brevity.

It will be apparent to the skilled person that the above
described implementations of the invention are not
exhaustive and variations on these structures may be
employed to achieve a similar result whilst employing the
same inventive concept. Individual elements within each

implementation can be replaced with any element or combination of elements which performs a similar function. For example, the grating element may be replaced with any suitable multi-frequency band filter. Further, the positions of the optically passive layer and the optically active layer may be interchangeable in some implementations (similar to the second implementation of the present invention). Consequently the fabrication process would need to be adapted.

Furthermore, it is also possible to implement non-waveguide forms of the invention, in which one or more of the ring laser cavity, the output coupling mechanism, the optical gain element, or the frequency selection means are not formed in waveguides.

It can therefore be seen that the present invention provides a tunable lasing device which has significant advantages over conventional devices.